III. *An Account of the Appearance of* Mercury, *paſſing over the Sun's Diſk, on the 29th of* October, 1723 *determining the mean Motion, and fixing the Nodes of that Planet's Orb.* By Edmund Halley, *LL. D. Aſtron. Reg. and R. S. S.*

THE Tranſit of the Planet *Mercury*, over the Diſk of the *Sun*, being one of the moſt curious and uncommon Appearances that the Heavens afford, our Aſtronomers, both at home and abroad, made due Preparation to obſerve, with the utmoſt Exactneſs, that which happened on the 29th of *October*, 1723, which I had predicted in the Year 1691 (*Phil. Tranſ.* N° 193.) would be, in Part, viſible in *England*. And the Sky proving, more than ordinary, favourable at that Time, we were enabled to obſerve the Ingreſs on the *Sun*'s Limb, with the greateſt Accuracy.

Accordingly, the ſame Day, *Octob.* 29. *ſtyl. vet.* at *Greenwich* in the *Royal Obſervatory*, I firſt perceiv'd, with my 24 Foot Tube, the *Planet* making a ſmall Notch in the *Sun*'s Limb at $2^h\ 41'\ 23''$ *T. app.* And at $2^h\ 42'\ 26''$ he was wholly enter'd, making an interiour Contact, the Light of the *Sun*'s Limb juſt beginning to appear behind his dark Body; which, notwithſtanding the Slowneſs of the Motion, was, in a Manner, inſtantaneous. Then, applying the *Micrometer* to the ſaid 24 Foot Tube, I open'd it ſo as to take in $16'\ 15''$ equal to the *Sun*'s Semidiameter at that time; and cauſing the northern Edge of the *Sun*, to move exactly along one of the Pointers, I waited till the Center of *Mer-*

Mercury came to move along the other, as I found it to do at $3^h\ 1'\ 16''$ *T. app.* But *Refraction* contracting this Difference of Declination about 5 Seconds (the *Sun* being then but about 11° high) I concluded that the Centers of the *Sun* and *Mercury*, were truly in the ſame Parallel of Declination at $3^h\ 3'$ *T. app. proxime.*

At *Wanſted* in *Eſſex* my worthy Collegue, the Rev. Mr. *James Bradly*, *Savilian* Profeſſor of *Aſtronomy*, obſerv'd with the *Hugenian Teleſcope*, of above 120 Foot long, the total Immerſion, or interiour Contact of the Limbs, at $2^h\ 26'\ 45''$ *T. æq.* that is $2^h\ 42'\ 38''$ *T. app.* twelve Seconds later than I found it at *Greenwich*; moſt of this Difference being due to the Difference of our Meridians. And applying the *Micrometer* to that vaſt *Radius*, he meaſured the Diameter of the *Planet* $10''\ 45'''$. At $2^h\ 48'\ 57''$ he found the Difference of Declination between the ſouthern Limbs of the *Sun* and *Planet* by the *Micrometer*, in a fifteen Foot Tube, to be $15'\ 19''$. Wherefore, allowing the obſerv'd Semidiameter of the *Planet*, and the *Refraction*, the ſaid Difference was neareſt $15'\ 30''$, and conſequently, *Mercury* more ſoutherly than the *Sun*'s Center in reſpect of Declination $0'\ 45''$.

Mr *George Graham*, in *Fleet-ſtreet*, *London*, obſerv'd the firſt Impreſſion on the *Sun*'s Limb at $2^h\ 41'\ 9''$ *T. app.* and at $2^h\ 42'\ 19''$ *Mercury* was intirely within the Disk. At $3^h\ 6'\ 41''$ he meaſur'd with a *Micrometer*, in a twelve Foot Tube, the Diſtance of his Center from the neareſt Limb of the *Sun* $2'\ 13''$. And again, at $3^h\ 25'\ 24''$ their Diſtance was found $3'\ 57''$. At $3^h\ 34'\ 43''$ he meaſur'd the Difference of Declination, from the northern Limb of the *Sun* $14'\ 57''$, which, corrected by *Refraction*, becomes $15'\ 4''$, that is, $1'\ 11''$ more northerly than the *Sun*'s Center.

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In the *Obſervatory* at *Paris*, *Signor Maraldi* obſerved the firſt Appearance of *Mercury* on the *Sun's* Limb at $2^h\ 50'\ 13''$ *T. app.* and the interiour Contact at $2^h\ 51'\ 48''$. And Mr. *de Liſle*, obſerving a-part, concluded the ſame at $2^h\ 51'\ 37''$, but ſuſpects it might have been ſome few Seconds later. This Gentleman has communicated his Obſervation at large, from whence we ſhall only borrow the following obſerved Latitudes.

h	′	″		′	″
At 2	56	20	*Latitudo Borea Mercurii*	3	36
3	00	40		3	42
3	10	20		3	46
3	16	12		3	55

At *Bononia*, in *Italy*, Signor *Manfredi* obſerved *Mercury* indenting the *Sun*'s Limb at $3^h\ 26'\ 22''$; and that he was gotten entirely within, at $3^h\ 27'\ 45''$. And theſe are the Obſervations moſt to be depended on, that we have receiv'd from abroad.

In order to deduce from this *Phænomenon*, ſo accurately obſerv'd, what may contribute to the Perfectioning of the Theory of *Mercury*'s Motion, which (as appears by the near Agreement of our Numbers with this and many other Obſervations of him) ſeems to need but very little Correction; I carefully computed, from our Tables, the Motion of the Planet in five Hours, and found his apparent Motion on the *Sun*, to be in Longitude $29'\ 21''$ Retrograde, and that his Latitude encreas'd northerly $4'\ 17\frac{1}{2}''$ in the ſame time; whence the Horary Motion in Longitude $5'\ 52''$, and in Latitude $0'\ 51\frac{1}{2}''$, and thence the Angle of the viſible Way with the Ecliptick $8^\circ\ 19'$, and the Horary Motion in that Way $5'\ 56''$. Again, the Angle of the Ecliptick with

with the Meridian, being in this Place 73° 24′, the viſible Way of *Mercury*, made an Angle of 65° 5′ with the Meridian paſſing through the Center of the *Sun*, whence the Horary Change of Declination becomes exactly 2′ 30″.

Theſe *Data* I chooſe rather to take from the Theory, than from immediate Obſervation; becauſe there is always an unavoidable, tho' ſmall Uncertainty, in what we obſerve, yet greater than there can be in the Computation for ſo ſmall a Space of Time, eſpecially now the Theory is, as I ſaid before, ſo very near the Truth.

This premiſed, let us now enquire the true Time of the central Ingreſs, and the Latitude of the Planet at that Time. And firſt, by my own Account, *Mercury* was gotten into the Parallel of the *Sun*'s Center, $21\frac{1}{2}$ Minutes after the central Ingreſs, in which Time he aſcended to the *Northward* 0′ 54″, and ſo much, therefore, was he more *Southerly* than the *Sun*'s Center at his Ingreſs. Mr. *Bradly*, $7\frac{1}{2}$ Minutes after the ſaid Ingreſs, in which the Planet aſcended 0′ 19″, found his Declination 0′ 45″ South, and therefore at the Ingreſs, his Declination was 1′ 4″ South. And by by Mr. *Graham*'s Obſervation, *Mercury* was more northerly than the *Sun*'s Center 1′ 11″, 53′ 20″ after the central Ingreſs; but in that Time, *Mercury* aſcended 2′ 13″, wherefore, according to him, at the Ingreſs the Planet had 1′ 2″ South Declination. We ſhall not therefore err above a Semidiameter of *Mercury*, if we aſſume his Declination, at that Time, to have been preciſely one Minute.

Now the *Sun*'s Semidiameter being then 16′ 15″, one Minute is the *Sine* of 3° 32′ in the Arch of the *Sun*'s Limb; and conſequently, the Point of this Ingreſs was 13° 4′ more northerly than the Ecliptick; whence the Latitude of *Mercury* was then 3′ 40″ North, and

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Difference of Longitude 15′ 50″, by how much he, at that Time, follow'd the *Sun*'s Center.

If therefore, to the Arch of 13° 4′, we add the Double of 8° 19′, or of the Angle which the viſible Way made with the Ecliptick, we ſhall have 29° 42′ for the Point on the *Sun*'s weſtern Limb, at which the Planet made his *Exit*, likewiſe to the North of the *Ecliptick*. Hence the Chord, deſcrib'd in the whole Tranſit, was of 137° 14′, and the Chord itſelf 30′ 16″; and the neareſt Diſtance to the *Sun*'s Center 5′ 56″. Now the Horary Motion in this Chord, being 5′ 56″, the whole Duration of this *Mercurial Eclipſe* becomes 5^h 6′ in reſpect of the Center of the *Planet*; and therefore the neareſt Approach of their Centers was at 5^h 14′ 30″ at *Greenwich*, and the *Exit* at 7^h 47′; both viſible in our *American Plantations*, had there been any curious Perſon there qualified to obſerve them.

It follows likewiſe, by the obſerv'd Diameter of *Mercury*, 10″ 45‴ that he was very little leſs than two Minutes of Time in paſſing the Limb; and, by the given neareſt Diſtance to the *Sun*'s Center, it is concluded that he was in Conjunction, in Point of Longitude, at 5_h 23′ 15″ having then preciſely 6′ 00″ North Latitude. Nor can it be doubted, but that all this would have been found exceeding near to Truth, had not the too early ſetting of the *Sun* deprived all *Europe* of the deſirable Sight.

There being a very remarkable *Period* of the Motion of *Mercury* in 46 Years, in which Time, he makes 191 Revolutions about the *Sun*; this Tranſit of ours is found to have been preceded by two others at that Interval: The firſt, in the Year 1631, when *Gaſſendus* at *Paris*, on the 28th Day of *October*, *ſtyl. vet.* was the firſt that ever obſerv'd this Appearance of *Mercury* within the *Sun*'s Disk, and found him to paſs off

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at 10^h 28′ *mane*. The ſecond was, *Octob.* 28° 1677, when myſelf had the good Fortune to obſerve both the Ingreſs and Egreſs of the Planet in the Iſland of *St. Helena*; the middle Time, when he was neareſt to the *Sun*'s Center, being there but 3′ 50″ paſt Noon, and the viſible Duration of the Tranſit of the Center of the Planet 5^h 14′ 20″; which was ſome ſmall matter contracted by Parallax, and moſt likely might have been 5^h 15′ 00″ without it. Now in 5^h 15′, *Mercury* deſcrib'd the Chord of 146° 52′ in the *Sun*'s Limb, being 31′ 9″, and conſequently the neareſt Diſtance to the Center was 4′ 38″, or the Sine of 16° 34′ the *Sun*'s Semidiameter being Radius; that is, 1′ 18″ leſs than we found it in 1723. Hence alſo it follows, that the true Conjunction in Longitude was 7 *min.* of Time later than the neareſt Approach of the Centers, *viz.* at 0^h 10′ 50″ at St. *Helena*, or at 0^h 35′ paſt Noon at *Greenwich*: and, that the North Latitude of the Planet, at that Time, was 4′ 41″.

Suppoſing, therefore, the neareſt Diſtance of the Centers in the Tranſit of 1631, to have been 3′ 20″, that is, 1′ 18″ leſs than in 1677, we ſhall find that *Mercury* then deſcrib'd a Chord of 156° 20′, traverſing the Diſk of the *Sun* in 5^h 21′ 30″; ſo that ſuppoſing his *Exit* at 10^h 28′ at *Paris*, that is 10^h 18′ 40″ at *Greenwich*, he enter'd on the *Sun* at 4^h 57′ 10″ in the Morning; and was neareſt his Center at 7^h 38′ *T. app.* but in the ſame Longitude with him at 7^h 43′, or *Octob.* 27° 19^h 43′ *T. app.* having then 3′ 22″ North Latitude.

And here, I think I may, without Vanity, advertiſe the Reader, that above thirty Years ſince, *viz.* in *Philoſoph. Tranſ.* N° 193, for the Month of *March*, *&c.* 169$\frac{9}{10}$, I predicted, by Help of the two former, this laſt Tranſit, with a ſurpriſing Exactneſs,

even beyond my Hopes, making the Time of the middle, or neareſt Approach of the Centers of the *Sun* and *Mercury*, *Anno* 1723, *Octob.* $29^d\ 5^h\ 19'$ *T. app.* which we found by Obſervation at $5^h\ 14'\frac{1}{2}$, only $4'\frac{1}{2}$ Minutes ſooner; and, in Latitude, *Mercury* was but ſix Seconds more ſoutherly than I then had computed it; the Error, in Longitude, being little more than two Diameters of this exceeding ſmall Planet; and, in Latitude, but a ſingle Semidiameter thereof. So, that for the Future, Aſtronomers may truſt my Table of theſe Tranſits, in *Tranſact.* N° 193, to a few Minutes of Time, and not wait with the Uncertainty of Hours, nay Days, as has lately been done.

But, in order to obtain a yet further Degree of Exactneſs by Help of this Obſervation, it may be moſt expedient to compare with it the Ingreſs I obſerv'd at St. *Helena*; becauſe, in that, as well as in this, the Latitudes of the Planet being very ſmall, a little Error in them will not ſo much affect the Longitudes. Suppoſing therefore, that *Anno* 1677, *Octob.* $27°\ 21^h\ 26'\ 15''$ at St. *Helena*, or $21^h\ 50'\ 15''$ *T. app.* at *Greenwich*, the Center of *Mercury* entered on the *Sun*, and that, at that Time, he was $8\frac{1}{4}$ Degrees on the *Sun*'s Limb, to the North of the Ecliptick (according to what is above concluded) it follows, that he had then $2'\ 20''$ North Latitude, and $16'\ 5''$ greater Longitude than the *Sun*'s Center; as in this preſent Tranſit, *Octob.* $29°\ 2^h\ 41'\ 30''$ *T. app.* at *Greenwich*, he had $3'\ 40''$ North Latitude, and $15'\ 50''$ more Longitude.

Now the apparent Geocentrick Differences of Longitude, are to the real Heliocentrick Differences, as the Planet's true Diſtance from the *Sun*, to his Diſtance from the *Earth*; that is, in both Caſes, as 313 to 676; wherefore, in 1677, *Mercury* wanted $34'\ 45''$ of the Conjunction with the *Sun*; and, in 1723, but $34''\ 13'$,

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at the Times of his apparent Ingreſs on the Disk. And, equating the Times, I find, that the *Sun*, *Anno* 1677, *Octob.* $27^{d}\ 21^{h}\ 34'\ 20''$ *T. æq.* was, in ♏ $15^{\circ}\ 36'\ 55''$ and, conſequently *Mercury*'s Heliocentrick Place ♉ $15^{\circ}\ 2'\ 10''$: and, *Anno* 1723, *Octob.* $29^{d}\ 2^{h}\ 25'\ 30''$ *T. æq.* the *Sun* was in ♏ $16^{\circ}\ 39'\ 43''$, and therefore *Mercury*, at that Time, in ♉ $16^{\circ}\ 5'\ 30''$.

Mercury therefore, in 46 Years with 11 Intercalations, and beſides $1^{d}\ 4^{h}\ 51'\ 10''$, has made 191 Revolutions to the Equinoctial Points, and over and above $1^{\circ}\ 3'\ 20''$. But, by the *Scholion* to *Prop.* XIV. *Lib.* III. *Natur. Philoſoph. Principia Math.* the Motion of the *Aphelion* of *Mercury*, from the Equinox in that Time, is $40'\ 18''$; ſo that there remains $23'\ 2''$ of *True Anomaly* to be reduced to the *Mean*: Now the Mean Anomaly of *Mercury*, in both Caſes, being 5 *ſig.* 12°, $23'\ 2''$ of True Anomaly gives $15'\ 24''$ Mean Anomaly; which added to $40'\ 18''$ becomes $55'\ 42''$, for the Mean Motion above ſo many Revolutions: and this is to be encreaſed by $8''$ to reduce it to the Plane of *Mercury*'s Orb, in all $55'\ 50''$.

Hence, doubling the Interval, in 92 *Julian* Years $1^{d}\ 9^{h}\ 42'\ 20''$, the Mean Motion of *Mercury* from the Equinox is $0^{s}\ 1^{\circ}\ 51'\ 40''$, from which, taking $5^{\circ}\ 44'\ 50''$ the Motion in $1^{d}\ 9^{h}\ 42'\ 20''$, we have his Motion in 92 *Julian* Years $11^{s}\ 26^{\circ}\ 6'\ 50''$, and in 100 Years, $2^{s}\ 14^{\circ}\ 2'\ 13''$, which is but $20''$ more than I had ſome Years ſince printed it, in my Aſtronomical Tables ſhortly to be publiſhed, and differs but one Hour's Motion therefrom in 3000 Years.

The forementioned Proportion of the Diſtances, *viz.* 313 to 676, is alſo between the Latitudes ſeen from the *Earth* and the Inclinations, or Heliocentrick Latitudes of the Planet: ſo that $2'\ 20''$, at the Ingreſs of 1677, gives $5'\ 2''$; and $3'\ 40''$ in 1723, becomes $7'\ 55''$

for the Latitudes at the *Sun*. And the Inclination of the Orb of *Mercury* to the Plane of the Ecliptick (determined by accurate Obſervations near his northern Limit) being 6° 59′ 20″, we compute the Diſtance of the Planet from his Node, in the former 0° 41′ 7″, and, in the latter, 1° 4′ 37″; which, being deducted from his Heliocentrick Places reſpectively, leave the Place of the aſcending Node, in 1677, ♉ 14° 21′ 3″; and, in 1723, ♉ 15° 0′ 53″: So, that in 46 Years the Node is found 39′ 50″ forwarder in the Ecliptick; which is but 1′ 30″ more than the Præceſſion of the Equinox in the ſame Time. We may therefore ſafely aſſume the Plane of the Orb of *Mercury* to be immoveable in the Sphere of fix'd Stars, and its aſcending Node to be ♉ 15° 41′ from the *firſt Star of* Aries. Nor can ſo very ſlow a Motion (ſuppoſing ſuch to be) be fully defined, but by the utmoſt Care and Diligence of future Aſtronomers, after the Obſervation of many Ages.

As to the reſt of the Theory of this Planet's Motion, I make his mean Diſtance from the *Sun*, 38710 ſuch Parts as the mean Diſtance of the *Sun* and *Earth* is 100000; and his greateſt Equation 23° 42′ 37″. The *Epocha* of his middle Motion, *ineunte Anno* 1723, *ſtyl. vet.* from the Equinoctial Point, I make ♐ 19° 9′ 31″; and that of his Aphelion to the ſame Time ♐ 13° 3′ 34″: the Aphelion moving *ſecundum Seriem Signorum*, ſeven Minutes in eight Years. And theſe Numbers I preſume, may repreſent the Motion of *Mercury*, with an Exactneſs equal to that of any of the other Planets; perhaps as near as the *Sun*'s Place by any Tables, or thoſe of the fixed Stars by any Catalogue yet extant.

It were to be wiſhed, that ſome good Obſervation, like this, had been made of the like Tranſit of *Mercury* at his other Node in *April*, where he was ſeen in-

deed *April* 23° 1661, but ſo imperfectly, that neither Ingreſs nor Egreſs was any where obſerv'd; and, though it be certain, that he traverſed the *Sun* on *April* 26°, 1674; and again *April* 24, 1707, yet we were ſo unfortunate, that the Conjunction in both happened ſo near Midnight, that he eſcaped unſeen by all the Aſtronomers of *Europe*, excepting ſingly Mr. *Roemer* at *Copenhagen*, whoſe Obſervation I have lately received by the Favour of Mr. *De l' Iſle* the Aſtronomer, communicated in the Words of the Manuſcript Journal of Obſervations of the ſaid Mr. *Roemer*. " *Hodie ſexto Maii* (*Anno* 1707) *horæ matutina* " 4^h 19′, *ſpectabatur Mercurius in extremo margine* " *Solis jamjam exiturus*; *altus ſupra imum ſolis* " *marginem* $\frac{1}{4}$ *diametri ſolaris*, & *ad ſiniſtram in* " *Tubo* (*ſc. invertente*) *Accuratius hæc determi-* " *nare non licuit ob moram nimis brevem.*" It was great Pity, that he did not, at leaſt, eſtimate, how many Diameters of his Body he was diſtant from the Limb of the *Sun*, or what Part of a Diameter, if ſo near: But having examined this Obſervation, I find that the *Sun*, at that Time, was but juſt riſen, or rather riſing, and ſoon after entered into a Cloud, ſo that the Limb of the *Sun* could not be diſtinctly ſeen, it always undulating and ſparkling much, when ſo near the Horizon; in which Circumſtance, a juſt Obſervation could hardly be made.

Let us now ſee how our Numbers, corrected as above, will repreſent this Obſervation. *Anno* 1707, *April* 24° 16^h 19′ at *Copenhagen* is 15^h 28′ at *Greenwich*, but 15^h 24 20″ *T. æq.* To this Time, I find the *Sun*'s true Place ♉ 14° 50′ 1″, and his Diſtance from the *Earth* 101005. The correct *Epocha* of *Mercury*'s mean Motion, for the Year 1707, is 3^s 13° 18′ 45″, to which adding, for the reſt of the Time, 3^s 19° 9′ 28″,

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we ſhall have his middle Motion at the Time of the Obſervation ♏ 2° 28′ 13″; and, taking his *Aphelion* in ♐ 12° 49′ 49″ therefrom, we have his mean Anomaly 10ˢ 19° 38′ 24″, and thereby the Equation to be added 12° 39′ 41″, and thence the Place of *Mercury* in his Orb ♏ 15° 7′ 54″. But the correct Place of the deſcending Node is ♏ 14° 46′ 25″, and therefore *Mercury*, being 21′ 29″ paſt the Node, had 2′ 36″ South Latitude at the *Sun*; and his Place, reduced to the Ecliptick, was ♏ 15° 7′ 45″, that is, 17′ 44″ paſt the Conjunction of the *Sun*, which diminiſhed in the Proportion of 5567 to 4533, or of the Diſtance of the Planet from the *Earth* to his Diſtance from the *Sun*, becomes 14′ 27″; and by ſo much was he paſt the Conjunction as viewed from the *Earth*. Again, by the ſame Proportion, his Geocentrick Latitude, at that Time, was 2′ 7″ South; and therefore, his apparent Diſtance from the *Sun*'s Center, was 14′ 37″; that is, but 1′ 18″ from his weſtern Limb; ſo that he might well be ſaid to be, *jamjam exiturus*.

But, that *Mercury* ſhould at that Time be ſo far northerly, as Mr. *Roemer*'s Words import, was abſolutely impoſſible; and, I am apt to believe, that ſo acute an Aſtronomer as Mr. *Roemer* was, could not himſelf be the Obſerver, but ſome Perſon leſs acquainted with theſe Matters; which the Words *ſpectabatur Mercurius*, inſtead of *Mercurium vidi*, ſeem to import. If he had then had North Latitude, he muſt needs have been ſeen in the *Sun* in *April* 1720, which we are aſſured he was not.

Laſtly, it may not be amiſs to advertiſe, that on the laſt Day of *October* 1736, *Mercury* will again traverſe the northern Part of the *Sun's* Disk, both Ingreſs and Egreſs being viſible to all *Europe*.

F I N I S.